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METAL-MINE FIRES AND VENTILATION

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D. HARRINGTON

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METAL-MINE FIRES AND VENTILATION[1]

By D. Harrington[2]

Metal-mine fires in the United States are not of frequent occurrence and relatively few of those that do occur result in loss of life, although many cause heavy property loss or are costly to extinguish. Over a span of years, however, more lives are lost in metal mines from fires than from any other of the untoward occurrences which afflict metal mining, such as electrical storms, floods, cave-ins, magazine explosions, or strikes. In perhaps more than 90 per cent of the fires in metal mines there is no loss of life; hence, the general public, even the general mining public, seldom hears of these fires, though the property loss frequently reaches hundreds of thousands of dollars; on the other hand, in some instances the property damage from an underground metal-mine fire has been negligible and the loss of life comparatively high.

In any comprehensive study of metal-mine fires, ventilation is certain to be found a vital factor. The influence of ventilation on fires and the influence of fires on ventilation are of vital importance. In metal-mine fires very few persons meet death from actual contact with heat or flame; nearly all fatalities are due to asphyxiation or suffocation. A well-planned, well-installed, and well-operated mechanical ventilation system is unquestionably one of the best available present-day protections from loss of life and property in case of fire in a metal mine; that this is true is attested by the usual helplessness of mining officials in trying to handle underground fires in a mine that has not had the foresight to install mechanical equipment to control underground air flow. On the other hand, the establishment of high-velocity air currents without sufficient day by day attention to such details as the method of coursing, or controlling, or confining them most certainly tends to increase dangers from fires rather than to aid in the avoidance or elimination of these dangers; the truth of this latter statement is shown by the fact that the greatest loss of life in metal-mine fires during the past 20 years has been in relatively well-ventilated workings, and in every case the life loss has been due to some more or less trivial or easily remedied defect in the ventilating system - usually a defect that has had some reference to doors used or supposed to be used to deflect or control air currents.

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[2] Read before the Mining Section, National Safety Council, Washington, D. C., October 4, 1932.

[2] Chief engineer, safety division, U. S. Bureau of Mines.

In a study of loss of life in metal-mine fires in the United States it appears that in the period 1916-1922, inclusive, approximately 240 lives were lost through fires, but since 1922 only approximately 20 persons have been killed from that cause. As far as can be ascertained from available records, approximately 600 lives have been lost in metal-mine fires in the United States to date. This does not appear to be a very impressive total until one realizes that in one of these fires 163 lives were snuffed out, in another 47, and in another 21, and that these three fires with relatively heavy individual life loss all have occurred within the past 17 years. In addition, the Hollinger gold mine in Ontario with underground operating conditions and practices similar to those of metal mines in the United States lost 39 lives in an underground fire in 1928, keeping to the front the fact that our metal-mining people still have a heavy hazard from fires even though they have caused the loss of relatively few lives in the United States since 1922.

Few mining companies, coal or metal, care to divulge the facts connected with fires or with any kind of accidents at their properties; hence, available information is meager, not only as to the number of fires but also the conditions which caused the fires or under which they were extinguished or otherwise controlled. The forces of the safety division of the Bureau of Mines for over 20 years have been on the alert to obtain data about all kinds of accidents in mining, and these include fires or explosions. During recent years the field men of the safety division have annually been present at or shortly afterwards visited the scene of about 35 explosions and 25 fires in mines, a few of the explosions and about one-fourth of the fires being at metal mines; however, there is good reason to believe that at least 100 fires occur annually in the metal mines of the United States when these mines are operating at even moderate capacity.

Unquestionably the most dangerous aspect of the fire hazard at metal mines is the far too prevalent idea among metal-mining people that their particular mine is not subject to fire, that there is virtually nothing in the mine which could burn, that the product mined is incombustible, or the mine is too wet for a fire to get a start; these and dozens of other equally falacious reasons are given for not expending any considerable amount of time or funds or effort in safeguarding against fires or for not providing for the handling of one if it should occur. As a matter of incontestible fact there are few underground mines in the United States which are not subject to numerous fire hazards; practically all underground mines (coal, metal, or nonmetallic) have combustible material in them such as timber, explosives, oil or gasoline, insulated electrical wiring or equipment, or similar materials the burning of very small quantities of which underground can easily result in many deaths; and in addition some metal mines have combustible shales or pyritic ores which may fire spontaneously, or have explosive gas, and far too many have flammable surface structures or heavy growths of dry grass or shrubs so near the entrance that if fired they would be likely to send poisonous gases into the mine and endanger the lives of all underground. In addition to the fact that practically all underground mines have in them ample combustible material to cause heavy loss of life in case of fire, practically all underground metal or nonmetallic mineral mines have in them numerous possible sources of ignition such as open lights and smoking, open-arcing types of electrical apparatus, and, in some mines, gasoline or other internal-combustion engines, blow torches, and other devices or equipment which give off flames.

In a study of the source of more than 100 metal-mine fires which occurred in the United States prior to 1922 it was found that about 35 per cent were caused by ignition of timber by candles, about 10 per cent were from using heat to warm oil or explosives or for some similar purpose, about 10 per cent from flame or gases sent underground from burning surface structures, about 12 per cent from spontaneous combustion (from timber splinters or bark, stored hay or manure, carbonaceous shales, pyritic ores, oily waste against timber, etc.), about 7 per cent from electricity, about 3 per cent from explosives, about 3 per cent from carbide lights against timber, and about 20 per cent from unknown or miscellaneous causes including incendiarism, lightning, etc. In the foregoing it will be noted that open flames - including lighted candles, carbide and oil lamps, and fires for heating and other purposes - were responsible for at least 58 per cent of these underground fires, electricity for but about 7 per cent, and that spontaneous combustion, explosives, and unknown causes accounted for the other 35 per cent.

In a study of a considerable number of metal-mine fires in a certain very active and progressive metal-mining section of the United States in which scores of fires had occurred, it was found that those which were dated before 1917 were caused about as follows: 50 per cent by candles and oil lamps, 2 per cent by carbide lights, 10 per cent by heating or other fires, 4 per cent by electricity, 4 per cent by smoking, and the remaining 30 per cent by unknown or miscellaneous agencies such as lightning, use of explosives, spontaneous combustion, friction, etc. Here again open flames of various kinds caused at least 66 per cent of the fires, while electricity caused but 4 per cent. Data were at hand on a larger number of mine fires in this region subsequent to 1917 than those above described for the period up to 1917, and the causes were essentially as follows: Electricity 40 per cent, carbide lamps 10 per cent, open fires for heating and other purposes 12 per cent, smoking 11 per cent, and welding torches 4 per cent; the remaining 23 per cent were unknown and miscellaneous causes such as spontaneous combustion, lightning, friction, etc. The above data cover more than 100 metal-mine fires in one metal-mining region with conditions which might be interpreted as against rather than in favor of easy or frequent occurrence of fires; the cost of fire fighting has been enormous in this region, though loss of life has been relatively slight. It is significant that with the virtual disappearance of the candle from the mines about 1916, the percentage of fires caused by the miner's light dropped from about 52 per cent in the period before 1917 to about 10 per cent in the period subsequent to 1917, though the percentage caused by carbide lights rose from 2 per cent for the period before 1917 to 10 per cent for that after 1917.

Perhaps, however, the most significant trend shown in these figures is that indicating that fires of electrical origin rose from about 4 per cent of those which occurred before 1917 to 40 per cent (or a tenfold increase) for the years 1917 to date; here it may be well to state that a considerably greater number of fires were studied in the latter than in the former period.

An attempt was made in one study on more than 100 metal-mine fires to locate the particular part of the mine in which the fires started. It was found that about 20 per cent started in the shaft and that in some cases the shaft was damp to wet; slightly less than 20 per cent started in a shaft, pump, or similar underground station and in at least half of the cases these places were damp to very wet; about 25 per cent started in timbered drifts or crosscuts; about 12 per cent in stopes; about 10 per cent in ore or waste chutes; about 3 per cent in raises; about 3 per cent in explosives magazines; and about 3 per cent in surface structures; the remaining 4 per cent had their origin in miscellaneous places such as mule barns, caved regions, etc. The fact that this particular study in which over 100 fires were involved showed that about 40 per cent were started in shafts or in shaft or pump stations gives a definite indication as to the advisable points at which the most definite fire preventive precautions should be taken; it is also significant that approximately 65 per cent of the fires in this region started in shafts, shaft or other stations, and drifts and crosscuts, all of which should be readily accessible for inspection purposes as well as for the application of fire-prevention installations and practices; in other words, it would appear that inspection and supervision were inadequate in the mines that had these fires.

The latest available data indicate that between 30 and 40 per cent of present-day metal-mine fires owe their origin to electricity. This percentage is likely to increase with the widening use of electric locomotives, pumps, and other equipment, as well as with the rapid introduction of electrically operated hoists, blower fans, slushers, drills and like equipment into stopes and other face regions in the mechanization of our mines. This would indicate that utmost care should be exercised in the selection, installation, and use of electricity underground, and certainly all electrical installations should be kept under the closest scrutiny and in the best of repair at all times. It seems also to be established that between 30 and 40 per cent of present-day fires in metal mines are due to smoking and to the use of carbide lights and other open fires or flames for various purposes; this seems utterly needless, and it is inconceivable that our metal-mining people should continue to take the "long chances" of the probable heavy loss of life or at least of property by fires started by open-light lamps, smoking, or use of open flame for any reason, where there are readily available far safer and far more efficient portable electric lamps for miners, smoking is utterly unnecessary and utterly reprehensible in a mine, and there is little or no necessity for having or for allowing open flame of any kind in any mine for heating, thawing, or for any other purpose except that possibly under some conditions and for limited periods a blow torch or an electric or acetylene welding apparatus may be used safely if reasonable precautions are taken. Evidently at least three-fourths of our metal-mine fires are now started by electricity, open lights, smoking, and flame used for heating or other purposes underground; this fact should indicate what precautions may be taken to avoid most of the present-day fires in metal mines. Many fires start just after the working shift leaves the mine; hence, it is important to have a fire patrol during nonworking periods and at least for the first hour or two after the working shift.

Below is a brief synopsis of the cause of several relatively recent metal-mine fires:

1. Some one, either on one of the levels or when coming up in the cage, threw a lighted cigarette butt away, and this started a fire.

2. Timber in an underground shaft gave way, breaking the electric wires that were in the shaft; as the shaft was very dry, the timber was ignited by the wires.

3. A miner or some other person going off shift threw a lighted piece of paper down a chute to see how much ore was in the chute. A fire resulted.

4. A fire was started close to the fan motor on one side of a shaft station by contact between a miner's carbide cap lamp and canvas tubing taking air from the fan to the raise where miners were at work.

5. A fire was caused by contact of an overheated incandescent electric-light globe with some "dope" used for a belt.

6. A match, presumably thrown by a smoker, started a fire in a station close to a timber shaft.

7. A fire was caused by a spark from a short circuit in the hinge on a knife-type trolley switch.

8. A pumpman, burning newspapers on a concrete floor in a pump room, set fire to adjacent timber in a mine.

9. The bark on a timber cap piece was fired, probably by coming in contact with a lighted carbide lamp on a miner's cap.

10. A candle used for illumination was left burning by a miner and caused fire.

11. The contact of a trolley wire with the cap of a sagging set of timber in a wet drift, which was being crushed, caused a smoldering fire which gave off considerable volumes of dense smoke.

12. Carbonaceous shale which throws off methane was encountered in a shaft sunk in driving a tunnel for the water system in a big city. The shaft was so wet that the workers had to use rubber boots, slickers, rubber caps, and hats. The methane was ignited by an open light and the resulting flames came in contact with timber; notwithstanding the fact that water was pouring in the shaft, the timber was ignited and burned briskly.

13. Fire was started by the contact of electric wires with 12 by 12 inch timber, probably due to defective insulation.

14. A small transformer and a starting compensator ran hot, setting fire to a wooden frame, which was burning when the fire was discovered.

15. Men were using an acetylene torch in a pocket of the shaft station and went away. Later on fire was found.

16. One report said: "It did not seem possible that a fire could occur in this shaft. The timber burned, and the mine is wet." The fire was caused by a short circuit in the electric-power cable.

17. A fire was caused by an overheated resistance on one of the electric tuggers used for slushing ore.

18. Fire was found in a raise 80 feet below the 300-foot level at a point where spent carbide was thrown.

19. Lighted powder wrappings thrown into a chute in ascertaining how much dirt was left caused a fire.

20. Sparks from a railroad locomotive set fire to the wooden headframe on the surface. Hot embers from the headframe fell into the shaft and burned it out.

21. The open flame of the lamp of a man who was recovering some tools that he had hid in a place where there was some dry lagging probably came in contact with timber and was the cause of a costly shaft fire.

22. It was determined that a shaft fire was started by a carelessly thrown cigarette, although there was a "no smoking" rule in the mine at the time. Very frequently the "no smoking" rule supposedly in effect in and around mines is most flagrantly violated by the mine foreman or the shift boss.

23. Fire was caused when the rope on a slope ran against the bearing on a roller and heated the oil that was in the roller bearing. The burning oil set fire to the nearby ties, causing a costly and destructive fire.

24. A lighted carbide lamp which a powderman placed on a shelf under a large fuse box started a fire by igniting the paper between the boards.

25. A trolley wire had fallen, and not being sufficiently grounded to operate the circuit breaker at the shaft, it heated, caused the insulation on the feeder wire to burn, and started a fire in the shaft. In a number of instances trolley wires have been down, set fire to cables, or set fire to cable insulation which carried the flame some distance to timber and caused fires.

26. A match or burning tobacco from a pipe started a fire.

27. Current was left on the controller of a sinking hoist; the hoist motor became overheated and the timber foundation began to burn. (Why have electrical machinery on timber foundations? It is almost universal practice for temporary installations underground, but should not be allowed.)

28. Blasting of cribs in top-slicing work or in cut-and-fill work or blasting of posts where the timber mat is following has caused many severe and costly mine fires, although they have not resulted in very great loss of life.

29. Some posts which were being blasted out to bring down the overlying material in a mine using a caving system caught fire, undoubtedly from the fuse, and before the fire was brought under control the entire mine had to be flooded, entailing an enormous loss to the company. The cause is apparent, though the answer is not quite so easy. The use of permissible explosives is recommended for blasting of timber; and where it can possibly be done, the blasting of timber electrically rather than by the use of fuse is advisable.

30. In some mines fires have been started by dynamite used in large charges in high sulphide ore (in which sulphur content is 30 per cent or over); in some cases there have been explosions very much like those which occur in coal mines.

31. The wiring of an electrically operated blower fan supplying air to the face of an exploration drift started a fire because of squeezing ground with short-circuiting of the wires.

32. An oil switch controlling the power lines of a metal mine in some manner "failed" and started a fire at the shaft collar on the surface. The flames spread into the mine and caused severe property loss.

Timber is by far the most widespread combustible in metal mines, and under certain conditions will burn whether in place in workings or only piled ready for use; whether wet or dry; whether in form of crushed decaying mat or in solid posts, caps, or girts; or whether in an absolutely open space or in an abandoned back-filled stope. A remarkably small amount of burning timber, such for instance as four or five timber sets, can give off a sufficiently large quantity of poisonous fumes to kill scores of people. Sulphide ores in a finely divided state burn readily, especially if in contact with burning timber; and copper and iron sulphides appear to burn much more readily than lead or zinc sulphides. A most difficult fire encountered in metal mines is one in a timbered stope back filled with waste-rock material, especially that containing considerable percentages of finely divided copper or iron sulphides. Other flammable materials which have aided in starting or extending metal-mine fires are gasoline, oil, and grease kept in open places underground.

Leaving piles of bark, chips or shavings of timbers in exposed places, or throwing empty explosive boxes, excelsior, sawdust, manure, spoiled hay, oily waste, old clothing, and refuse into abandoned workings - all these careless practices have resulted in starting or in aiding the extension of destructive fires.

At all mines that have flammable surface structures near the entrances, fire doors should be provided to prevent fumes or fire from being drawn into the mines. Flammable surface structures should not be closer to a mine opening than 100 feet, but if already at or near the mine opening such structures should be fireproofed by gunite or some other method and thoroughly protected by readily available water lines such as hose, sprinkler systems, and fire extinguishers, the equipment to be kept in good working condition by periodical testing. Combustibles should as far as possible be kept out of structures near mine openings, and the use of fires, matches, and smoking materials in mines or in flammable structures near the openings to mines should be prohibited or at least very definitely restricted.

Intake-air shafts are generally dry and if timbered constitute a continual fire hazard. It is noteworthy that a large proportion of fires in metal mines originate at or near shafts. Downcast shafts should be of concrete construction, and where this is not feasible timbered shafts and shaft stations should be fireproofed by gunite or other means. In the fireproofing process it is desirable to make the shaft lining smooth, as this greatly facilitates the flow of air.

In fireproofing by gunite it is advisable at intervals of approximately a hundred feet (preferably just above stations) to take out about one set of timbers around the shaft perimeter and concrete back to the rock walls to prevent creep of fire in timber behind the gunite.

Where it is not deemed feasible to fireproof downcast timbered shafts by concreting or guniting or other effective method, the shafts should be thoroughly protected by sprays, water pipe with fusible plugs, or perforated pipe, and with suitable placed valves, so that in case of fire in the shaft any section may readily be drenched with water. Preferably, the water lines should be controlled from the surface, and there should be suitable pressure-reduction valves and signboards denoting the exact location of control valves. There should be on important shaft stations at least 50 feet of fire hose connected to the water line, with nozzle attached and with valve controls near at hand (well designated by signboards), in order that water may be always available for use without delay at the stations or in the shafts. Care should be taken that water used in shaft fires should be so applied as not to reverse air currents and thus possibly cause loss of life. Where the ventilating current is weak, an upcast air current can be reversed to downcast by the spraying of a relatively small amount of water into a shaft.

Timber upcast shafts which are usually damp or wet, or downcast shafts in which some or all of the timber is damp, may burn readily if fire gets a good start in a dry, heavily timbered station or other adjacent working. Hence, fire protection and fire prevention should not be neglected, even in upcast shafts, or where the timber in a shaft or station is usually damp.

Since many fires in timbered shafts are started by electric wires, it is desirable, where feasible, to transmit electric power underground through drill holes; this is done satisfactorily in several places. Where power wires must be taken through dry downcast shafts, it is advisable to fireproof at least that part of the shaft containing the power wires and in any event such power wires should be very carefully installed to prevent leakage or short-circuiting of the current.

Electric trolley wires should not be allowed to be in contact with timber caps; wires carrying current should not be attached to timbers by nails, pieces of rope, and wires; electric motors should not (if it be possible to prevent it) be placed close to timbers or in heavily timbered stations or under heavily timbered stopes or raises, and if they must be in such places the immediate surroundings should be fireproofed (by gunite, concrete slabs, or otherwise). Electric-light globes should not be in contact with timber; fuses should not be bridged by heavy wires; circuit breakers or no-voltage release compensators should not be locked in place; and the usual slip-shod methods of installing mine electrical equipment and of making repairs on it should be supplanted by work of a nature at least as careful as that required for surface electrical installations. Suitable fire extinguishers or containers with sand should be readily available at or near all electrical stations in a mine and preferably just outside the station and on the intake or fresh air side of it.

Electric switches should be of the inclosed externally operated type of substantial and safe construction, attached to fireproof base; and the region around the base, as well as the region around the wires near the motor, should be fireproofed. Switches suitably designated by colored light or by signboard should be provided at reasonable intervals on each level so that current to electrical equipment or power lines may be cut off without delay; and electric current should be excluded from mines or parts of mines which are not being worked or kept under more or less constant supervision. Trolley locomotives should be superseded where possible by storage-battery locomotives. Where trolley wires are guarded by wooden

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trough, occasional sections of the trough should be made of noncombustible material, as fires have been transmitted several hundred feet along trolley guards in a drift otherwise devoid of timber.

Storage of even small quantities of oil, grease, gasoline, or similar flammable materials underground is dangerous, and if necessary should be done under lock and key in a fireproofed place isolated from travel way and air currents. These dangerous substances should not be allowed to lie around timbered shaft stations or other workings, as is common practice.

Similarly, explosives should be stored underground in a place isolated from ordinary travel and air currents, the "caps" and fuse at least 100 feet distant from the "powder," and should be issued by an attendant only at certain stated periods. These places should be kept clear of excelsior, paper, empty boxes, parts of boxes, and other refuse. All open lights should be absolutely excluded; the place being lighted either by the ordinary incandescent electric lights properly installed or by small "battery" lights. It is advisable to have fire patrol of working places immediately after blasting, especially where blasting is done in or close to timber. Where feasible, blasting should be done electrically rather than with fuse. In blasting timber, not more than five or six holes should be fired simultaneously at the same place, and it is advisable to use the coal miner's permissible explosives to decrease the fire risk. The greatest care should be taken in transporting explosives in bulk to the underground magazines and also in smaller quantities from the magazines to the working place.

Candles should be entirely excluded from mines except for the purpose of occasional testing of oxygen content of air; and the metal miner should learn to carry his carbide lamp in his cap as the coal miner does, for the use of the "candlestick" in holding a carbide lamp to timber post has been responsible for numerous fires. Notwithstanding the opposition to it, a "no-smoking" rule should be instituted and rigidly enforced in metal mines, and bosses as well as other underground employees should obey it. The present-day electric cap lamp is more efficient, less expensive, and far less hazardous than the acetylene lamp and by all means the metal miner should discard the open lights and use only up-to-date electric cap lamps for his portable lighting.

As every metal mine which has timber or other flammable material underground has a fire hazard, every such mine should take precaution to combat fire, and one of the most essential precautions is to have available - not only in shafts and shaft stations, but on important levels - water lines at least 2 inches in diameter and with suitable surface storage and valve control. The exposed threads on valves or water pipe in mines should be kept well greased or oiled to prevent undue corrosion; this is an important detail and one almost universally neglected. The practice of converting air lines to water lines is good, but care must be taken that locations of valves to accomplish the change are well marked, with full instructions by signboards at or near the valves. In deep mines where the head could be excessive, suitable pressure-reducing valves or other equipment should be introduced into lines or branches for attachment of fire hose, to hold pressure to less than 100 pounds per square inch at the hose.

If a fire can be directly and promptly attacked by appropriate means, it generally can be extinguished before much damage is done; hence, it is important to have available at critical points - important shaft or other stations - emergency equipment such as fire hose and extinguishers or a supply of sand or similar material. Of course, it is absolutely essential that such equipment or material be kept in working order by periodical try-out or rigid inspection and by the instruction of the men in its purpose and use.

There should be at least two openings through either of which men may escape without danger or difficulty when one is not available temporarily; if the mine is deep (say, 500 feet or over) and employs a considerable number of men (say 25 or more underground on one shift), two shafts should be available, each with hoisting equipment to the lowest levels, able to remove the men from the mine with minimum delay.

There should be more than one system of shaft signals, and if feasible, there should be a system of signaling from the moving cage. Telephones should be installed on important underground shaft stations and at important gathering places in the mine, and if feasible the telephone lines should be brought into the mine through some opening other than the one ordinarily used for handling men. Where it is feasible, air and water lines should be brought into the mine through two openings, to be available from one in case the lines are destroyed in the other.

Signboards, always kept in good condition, should be placed at comparatively numerous points underground to designate the direction to exits as well as to denote places of danger. New employees should be promptly acquainted by bosses with the location and best methods of reaching the various exits and should be required to use these exits at least once every few months, and the travel ways in these exits should be kept in safe and "travelable" condition.

There should be installed some system by which miners may be promptly notified of fire, and all employees should be informed as to the significance of such signal. Turning compressed air on and off, filling compressed-air lines with water, rapping on pipes, ringing of gongs, flashing of lights, use of telephones, and introducing some stench into compressed-air lines are the methods in use; the latter is one of the most efficient.

Probably the best and most effective method of protecting both life and property in case of fire is the establishment and maintenance of a carefully designed, efficient, mechanically controlled ventilation system with (1) air-tight doors so placed as to be able to isolate shafts from mine levels; (2) air splits held absolutely separate from each other - hence, able to confine smoke to but a small part of the mine; and (3) the main man way downcast or on the intake - hence, allowing escape in fresh air unless the fire is in the main travel way. Positive control of air currents at all times is essential, as even small defects in ventilation arrangements may be costly.

Leaky doors which only partly hold air at ordinary times and fire fumes in time of emergency, open levels between main intake and return shafts, or open raises of crosscuts between separate splits - and, in fact, anything which allows short-circuiting of air - is likely to be dangerous. Even the trolley slot in doors or doorways should be made as small as possible.

The following additional suggestions are made as to mine doors:

1. Mine doors and their frames should be substantially constructed, should be covered with roofing iron or otherwise fireproofed, should be tight, and should be always kept in repair.

2. Doors should close automatically after passage of men or cars and should have a latch or other positive means of keeping them closed, even though ordinary pressure on the outside of the door should become pressure on the inside, a situation likely to occur at time of fire.

3. Every main air course, whether shaft, incline or level, should have in place either within itself or in all the openings leading from it, a system of doors such that in case of emergency the entire shaft, incline, or level opening can be quickly isolated from other parts of the mine. This is especially important as to downcast, or intake timbered shafts, inclines, or level air courses. Doors should be provided for all main openings leading from main air courses (both intake and return); and when at ordinary times there should be free flow of air, the door should have a sign denoting that it is to be closed only in case of emergency (if possible giving the exact contingency under which the door should be closed).

4. All doors, but especially those for use during fires or in exits between mines, should close flush against the face of the doorframe instead of in a groove within the frame; this is to prevent sticking of door or inability to open or close it if there should be deformation of doorframe from ground movement or swelling of the door or frame.

5. Where there is necessity for frequent opening of doors controlling main air currents, or where such doors must remain open for long periods, it is advisable to have two or more doors placed so that when one must open, one or more may be closed and thus prevent passing of air.

6. All employees should be educated to respect doors and especially to close those which are supposed to be closed. It is advisable to have on each door a sign such as "Keep this door closed," or "Close this door in case of fire in main shaft," or other sign applicable to the specific condition existing at each door. Any employee failing to close a door which should be kept closed, or one who deliberately or carelessly breaks a door or its frame, should be disciplined, even to the extent of discharging him, if necessary.

7. It is extremely desirable that all mines be divided into air splits by doors, etc., in such a way that a fire in any one split will be held separate from all other splits and by manipulation of doors may be further isolated and controlled. In ordinary times, this system operates to the benefit of distribution of air currents to the places where men work.

Ventilating one mine through another is not advisable if other circuits are possible, for experience has shown that a fire in one mine may overcome or kill men in an adjacent connected mine. The mine which ordinarily delivers air to its neighbor may at time of fire receive deadly fumes through reversal of air currents. This danger from interventilation of mines is present whether the mines are owned by separate companies or by one company, and it exists to a certain extent where ventilation is mechanically controlled, though not nearly so much as where the ventilation is natural. Where two mines have been stoped along the boundary line, in some cases slime or sand filling may be used to make barrier pillars.

The main ventilating fan should be in a fireproof housing and, if possible, be placed on the surface and connected to mine openings by fireproof ducts. It should be equipped with a system of doors, at or near the fan, or with any other feasible method which will allow of changing direction of air currents with minimum delay. However, at time of fire, the ordinary direction of underground air currents should be reversed only after mature consideration of the effect upon those underground. The following hints are offered in connection with reversible fans and reversing of air currents:

1. All main fan installations at metal mines with fans on the surface should have the reversible feature, and where feasible, underground main fans should also have the same arrangement.

2. In addition to the reversing feature, all fan installations should be fireproof; and main air courses should be so equipped with doors that, if necessary, all air flow may be closed to or from the air course.

3. To make the reversing feature effective, mine doors should be so constructed as to remain closed, preferably by a positive latch, even when the direction of pressure against the door changes. Occasionally in normal times the reversing feature should be tested to make certain of its smooth working in case of emergency.

4. Booster or distributing fans in use in metal mines to distribute air to "blind ends" need not be reversible, but should be in a fireproof setting.

5. While there are instances of loss of life due to reversal of air currents, there are a greater number of instances of saving of both life and of property by use of reversing systems in both coal and metal mines.

6. Danger in reversing direction of air flow is much greater in coal mines than in metal mines, owing to the possibility of explosions, yet sentiment in coal mines is almost unanimous in favor of installing the reversing feature on main fans.

7. It is no more logical to condemn the use of the reversing feature in connection with main fans at metal mines because of one or two isolated cases of loss of life associated with reversal of air after a disaster than it is to condemn use of hoists for hoisting men because there have been a few hoisting accidents, or to condemn the use of electricity because there have been some deaths in mines from shock.

8. The cost of installing main fans with the reversing feature is but about 25 per cent greater than without it. The total cost for a fairly large mine would be less than $2,500, and for an ordinary mine not as much as $1,000. With use of this feature, the return in dollars and cents would probably be many times the costs just cited, and the value returned in saving of life might be incalculable.

9. The reversing feature can be used to facilitate ordinary mining operations. One deep metal mine in the West uses the feature to "cut" ice out of the operating shaft in winter, and converts the downcast operating shaft to upcast in less than 10 minutes.

10. Any metal mine, which for ordinary operations must for some reason maintain a main shaft or travelway as upcast, should certainly have the reversing feature on the fan, since a fire in almost any part of the mine may at any time fill the shaft with fumes and quick reversal of the direction of air flow would give underground men a safe exit through the shaft. Such shafts should also have doors at all intersections so located and constructed as to be able to isolate the shaft from all air flow if necessary.

11. Reversing the direction of air currents unquestionably has some possible dangers, some phases of which are herewith mentioned: (a) At time of fire or explosion, changes in direction of air flow should not be made except when it is fairly well established that good rather than harm will result.

(b) Mines with fans equipped to reverse direction of air currents seldom use this equipment; hence, at time of emergency there is likely to be undue delay in effecting the change, and in some cases the change can not be brought about due to inefficiencies in the installation.

(c) Mines having fans with the reversing feature rarely have underground doors so constructed that the reversal can be accomplished.

(d) When air currents are reversed in mines with high humidity and acid water they may cause damage to metal in downcast shafts when they are converted to upcast.

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(e) Mines with such fungus and timber decay in abandoned and partly ventilated workings tend to spread fungus spores; hence, in such mines timber decay is extended by reversing air currents.

12. In general, very few persons care to assume responsibility for changing air flow in a mine at time of disaster; moreover, very few have the special knowledge as to the feasible method of making the change. These conditions alone will, in general, safeguard the reversing feature from misuse.

13. The direction of main air currents should not be changed except under instructions from the mine foreman, superintendent, or other official who is familiar with the mine and its air currents, and who should also be sufficiently familiar with underground conditions at the time of making the change that he realizes the probable effect and feels able to shoulder the responsibility.

14. The placing of the reversing feature on main fans for metal mines is a cheap and effective method of providing insurance against loss of life and property in case of fire. It pays even if never used, and it is likely to yield big "dividends" in prevention of losses in case it is available and is used in an emergency.

Comparatively few men at metal mines understand methods of inducing or controlling the flow of air at ordinary times, and still fewer know how to handle the gases from a fire. It is a fatal mistake to assume during a mine fire that a man is safe in clear air so long as his carbide light burns. Men who were in air devoid of smoke have been found dead from carbon monoxide with their carbide lights burning brightly beside them. The candle or carbide lights burn brightly in air containing enough carbon monoxide to cause death in a fraction of a minute; however, a man can live in air containing too little oxygen to support the flame of a candle or a carbide light. A candle is extinguished when the amount of oxygen falls below 17 per cent, and the carbide light "goes out" when the oxygen is below 14 per cent; a man can exist for some time when the oxygen content of the air falls as low as 10 per cent, if no other harmful gases are present. A canary or a mouse is quickly made unconscious by a percentage of carbon monoxide in which a man can live for a short time; hence, when the canary drops, the man should take warning and retreat immediately. When venturing into air suspected of being impure, if the small animal (canary or mouse) lives and a candle or carbide light burns, a man is safe unless explosive gas is present, and this method of testing should be adopted in metal mines even in face of the ridicule usually offered when the animal is used.

When men are unable to escape to the surface at time of mine fire, they generally can aid materially toward saving themselves if they do not lose their heads by attempting to force their way through the smoke and gases.

By retreating to blind workings into which the smoke has not penetrated and tightly sealing off the openings to exclude the gases, using timber, posts, boards, plank, canvas, paper, mud, dirt, or even clothing to make the seal, men may live for days, especially if they have included within the sealed region one, two, or several hundred linear feet of fresh-air drift, have taken with them a supply of water and such food as they may have, use food, water, and light sparingly, and move about occasionally to keep the air within the sealed place properly mixed. The moving about is important, as otherwise the air may be locally depleted of oxygen where many men sit or lie still, and they may die for lack of oxygen, although plenty may be readily available 20 or 30 feet distant. In selecting a place to barricade, care must be taken to choose solid ground, as barricades placed in filled or broken ground are likely to admit gases, and at several fires have done so, with the resultant death of the men. Similarly, care must be taken to seal all openings and to keep the seals tight; in at least one instance men tried to seal themselves, but apparently did not see a raise; later, fumes entered through the raise and suffocated them.

Some mining companies now have underground refuge chambers with air-tight doors; in these chambers are placed barrels of water, compressed-air lines, compressed foods, and telephones. It is suggested that mines with bad fire hazards be equipped with such stations. Mines with only one opening to the surface should be required to have such refuge chambers for use in case of cave-ins and fires in the one opening.

Only too frequently a fire obtains so great a start that it is impossible to handle it directly, or it is in an inaccessible place, or in a place in which falling material prevents actual contact, and recourse must be had to other methods of attack. To control such fires, the most successful and acceptable method is to place seals of clay, sand, boards, canvas, or, preferably, concrete in such manner as to confine the fumes within a comparatively restricted area with minimum leakage of air into the region. As a rule this can be done only after much dangerous effort. Where the seals are made tight and kept so by constant watchfulness, and where the surrounding strata are not broken, the oxygen content of the air is soon depleted below the 5 or 6 per cent necessary to support combustion. If the region is then allowed sufficient time to cool before being opened, fires are generally controlled with minimum expense, though the cost may mount into the thousands or even into the hundreds of thousands of dollars.

Where an entire mine must be sealed or where territory with much open space (say 1,000,000 cubic feet or over) must be sealed, the process of extinguishing a fire by sealing is likely to be long drawn out and may not be feasible. This is especially true when any opportunity for air leakage exists, as through intersecting veins or connecting workings to other mines, or breaks or openings of any kind to the surface. In such circumstances other methods of control must be utilized, though in any event sealing is likely to constitute an important part of the process.

The usual method of overcoming a metal-mine fire where sealing is not effective is to flood it. This method is costly, both in actual performance and in subsequent effects. Sometimes steam is tried for extinguishing a fire, but generally with only limited success. At other fires some inert gas, such as carbon dioxide, is used. Water sometimes is introduced through diamond-drill holes and coursed through the area. Some fires of long standing have been overcome by the introduction of hundreds of thousands of tons of mill tailings through diamond-drill holes and other openings; this process usually accomplishes desired results, after sealing and other available methods have proved unsuccessful.

The cement gun is extremely useful in cementing broken ground to prevent escape of fumes, and also in making bulkheads of timber, rock, and boards air-tight, and even in constructing cement bulkheads.

Where fire is in moving or in heavy ground, rigid bulkheads of cement and rock are inefficient, and bulkheads of timber laid skin to skin can be held tight much more readily than cement and rock; with cement and rock bulkheads it is frequently advisable to construct the upper part and possibly the sides with clay to allow for movement without cracking the bulkhead.

All bosses, surface and underground, as well as clerks, timekeepers, and other employees, should be brought together into an organization to discuss possible fires from time to time, and to determine definitely what each should do in case of fire on the surface or at various places underground. There should be posted in the mine office and kept up-to-date a list of names and street and telephone addresses of persons to be notified in case of fire, including mine officials (manager, superintendent, and foreman), safety men, oxygen mine rescue apparatus men, state inspectors, doctors, and ambulance drivers. All bosses, cagers, motormen, drivers, and samplers should be made fully acquainted with location of valves and electrical switches and should be thoroughly instructed and regularly drilled as to the action to take at time of fire, first, toward assuring the safety of the men and, second, toward protecting property. Bosses and others familiar with the mine should be trained in the use of oxygen mine rescue apparatus and other similar equipment; and bosses, at least, should be familiar with mine-fire gases, the danger from them, and methods of detecting them. Above all other things, discipline of the strictest order should be maintained in all activities at or around a mine fire.

It is of extreme importance that material and apparatus on hand for use in case of fire be subject to rigid and efficient periodical inspection, and be given an occasional test under conditions approximating those of an emergency. It is exasperating, to say the least, to find that fire extinguishers are out of order, or hose spanners lost, or fire hose broken, or valve wheels displaced, after much dangerous effort has been made to get into position to fight a fire; and it is from delays caused by lack of proper attention to such details that many mine fires get out of hand. It is of particular importance, not only at emergency work on a new fire, but at the more long-drawn-out task of controlling an established fire, that orders respecting the fire fighting be issued preferably by some one person, thus preventing confusion due to duplication of instructions.

The establishment of an efficient mechanical ventilation system, as previously mentioned, is of great value in fighting a fire, and mechanical ventilation is now placed at many metal mines where its chief use is to be in connection with possible fires. In addition to having a large fan to control main air currents, some mines are equipped with small auxiliary fans on mine trucks with a supply of flexible tubing and other accessories; this permits controlling the ventilation locally from strategic points near an underground fire. Some mining companies combine ventilation doors with fire doors, and erect concrete jambs with metal doors at points well located to isolate main air courses, if desirable; this permits controlling the flow of air as well as the fire or fire fumes. It is desirable that these fire doors be so constructed as to cause the door to close against the side of the concrete frame or jamb rather than against a groove in it, in order that settlement of the surrounding area will not prevent the opening or closing of the door. It is equally desirable that the door have a positive latch by which it may be opened from either side; this latch should be of such construction that it will not rust tight or otherwise become inoperative.

Each mine should have always available a supply of canvas fire hose, with nozzle, to fit surface or underground water pipe; possibly a small fan with canvas tubing, and at least a dozen 3-cell electric flash lights with plenty of batteries and a number of readily portable fire extinguishers. A large mine should have at least ten sets of up-to-date oxygen mine rescue apparatus, with supply of oxygen and regenerators and possibly other equipment. If gas masks (respiratory apparatus which filter out noxious gases but do not supply oxygen) are used in connection with metal-mine fires the greatest possible care should be exercised against bringing them into atmospheres which are or which may readily become deficient in oxygen or which contain poisonous gases in excess of the filtering capacity of the mask; and in any case no person should be allowed to use any type of respiratory apparatus such as oxygen breathing apparatus, or gas masks, or even hose masks unless he knows the details of the operation of the apparatus and its limitations and also has had instruction and at least some practice in the wearing of the apparatus. Small mines or mines at which oxygen apparatus may not be available can secure the apparatus as well as supplies and the advisory services of men accustomed to fighting fires by applying to the nearest U. S. Bureau of Mines safety office, station, or car. If its location is not known, quick action can be had by wiring for help to the Director of the United States Bureau of Mines, at Washington, D. C., who will promptly notify the nearest available safety car or office.

Metal-mine fires with heavy loss of life occur relatively seldom, and while much is written and read and said about fires for a few weeks after occurrence of one which has caused heavy loss of life or possibly of property, in general mine fires and mine-fire data are given but scant attention between occurrence of fires. And when a mine fire occurs with unpleasant consequences it is almost invariably ascribed to an unavoidable chance or is called an act of Providence or of some other agency when as a matter of fact practically all mine fires are man-made and the result of gross carelessness. Moreover, their occurrence can be avoided, or at least loss of life in connection with them can be prevented, if every underground mine would frankly recognize that it has a fire hazard and would take measures such as are recommended in this paper for the avoidance of fires or for the safe and efficient handling of them if they should occur.

A relatively short bibliography is appended to this paper and from it can be selected much of the available metal-mine fire data published during the past several years.

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Candle fires. Vol. 94, 1912, p. 1204. Refers to fire in West Stewart copper mine, Butte, attributed to a lighted candle left near timber in a raise.

How mine fires are started. Vol. 96, 1913, p. 1233. Fire in iron mine started by lighting paper and throwing it down a chute to see how much ore was in it.

General alarm for mine fires. Vol. 97, 1914, p. 873. Recommends that a general alarm be sounded or given so that all men could be removed before workings fill with smoke.

The automatic sprinkler in metal mines. Vol. 114, 1922, p. 705. Suggests that trials be given.

Fire hits Northern Ontario again. Vol. 114, 1922, p. 662. Extensive surface fire burns mining properties and towns.

Fire escapes for mines. Vol. 114, 1922, p. 573. Loss of life caused through lack of escape ways.

An enemy of the mining industry. Vol. 114, 1922, p. 486. Review of some bad fires.

Safeguarding earnings from the fire hazard. Vol. 116, 1923, p. 365. Insurance covers fire at Hecla mine, Idaho.

Fire losses in the mining industry. Vol. 121, 1926, p. 195. Some fires of 1925 - mills. Increase in insurance rates and suspension of production.

The Hollinger fire. Vol. 125, 1928, p. 321. Questions asked - could tragedy have been averted or consequences lessened; what precautions were taken, warnings provided, fire doors were available?

More installations of mine-rescue apparatus needed. Vol. 127, 1929, p. 987. Brief history of use of apparatus in United States, particularly the promotional work of Bureau of Mines and the value of trained crews in time of fires.

Fire loss, President Hoover directs attention to. Vol. 128, 1929, p. 535. Fire risk at mining camps and plants; much carelessness; production suspended.

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Twenty-one dead in mine fire at Butte. Vol. 101, 1916, p. 302. Fire in Pennsylvania copper mine, February 14, 1916.

Fire hydrant used at Miami. Vol. 102, 1916, p. 790. For surface protection, swinging on a universal joint.

Fire protection in shafts. Vol. 103, 1917, p. 101. Water supply in fire zone, so chemical extinguishers were used.

Outside rack for fire hose. Vol. 104, 1917, p. 304.

Air-controlled fire door at Copper Queen mine. Vol. 105, 1918, pp. 559-560.

Fire protection of surface plants. Vol. 109, 1920, p. 883. Sprinkler system at Empire gold mine, California.

Committee recommends fire-control measures. Vol. 114, 1922, pp. 914-915. Findings of California committee.

Argonaut jury recommends connections between neighboring properties. Vol. 114, 1922, pp. 691-692. Result of disaster of August 8, 1922, when 47 men were asphyxiated.

Mine-fire control safety orders - issued in California. Vol. 115, 1923, pp. 548-549. The complete text.

Work resumed after fire in morning mine at Mullan, Idaho. Vol. 115, 1923, p. 333. Fire at 1400 feet asphyxiated three miners on January 23, 1923.

Gunite as a fire preventive. Vol. 115, 1923, p. 192. Cites tests of U. S. Bureau of Mines.

Fire consumes Hecla's surface plant. Vol. 116, 1923, p. 118. Describes a fire which resulted in several hundred thousand dollars worth of damage in Idaho on July 13, 1923.

A new portable 40-gallon foamite fire extinguisher. Vol. 118, 1924, p. 836.

Two lose lives in unusual mine fire at Butte. Vol. 118, 1924, p. 470. Gasoline spilled at hoist set fire to building, headframe, and shaft.

"Helmet" men isolate new fire in Copper Queen mine. Vol. 118, 1924, p. 308.

Fire-pump controllers improved by manufacturer. Vol. 119, 1925, p. 1027. Notes changes made to meet the National Board of Fire Underwriters requirements.

Construction of mine-fire door. Vol. 119, 1925, p. 813. A fire was retarded by a door of wood and zinc-coated iron at Plymouth gold mine, California.

Fire protection at Butte mines. Vol. 120, 1925, p. 986. Review of report of U. S. Bureau of Mines.

Do fire drills pay? Vol. 121, 1926, p. 695. Affirmed at fire in Utica iron mine, Hibbing, Minnesota, May 2, 1926.

An improved fire signal. Vol. 123, 1927, p. 792. Tells of use of a triple siren on the surface.

Canadian Royal Commission and mine operators approach agreement on safety regulations. Vol. 125, 1928, pp. 665-666. Procedure on the Hollinger fire enquiry.

Coroner's jury emphasizes negligence of Hollinger executives. Vol. 125, 1928, p. 543. The negligence lay in allowing flammable material to be dumped in old stopes and in not having all old stopes cleaned out.

Hollinger enquiry marked by conflicting evidence. Vol. 125, 1928, p. 427. The dumping of flammable refuse underground was known to bosses and others; the safety inspector did not consider this in his province.

Pointers on precautions against mine fires. Vol. 125, 1928, p. 741. Answer to question on safe practices underground.

Fire-gas at Hollinger kills 39. Vol. 125, 1928, pp. 308-309. Burning refuse in stope above 500-foot level asphyxiates 39 men on February 10, 1928.

Danger at Hollinger not realized. Vol. 125, 1928, p. 951. Review of the commissioner appointed to enquire into this fire which asphyxiated 39 men.

Ontario makes fire hazard survey. Vol. 125, 1928, p. 552. What the Provincial Government started.

Ventilation and mine fires. Vol. 125, 1928, p. 459. Deductions from fires in Hollinger and Magma mines. Carelessness of workers; exacting inspection; placing of fire-fighting equipment in critical places.

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